

GASEOUS ABUNDANCES IN M82

P. Ranalli¹, L. Origlia², A. Comastri², R. Maiolino³, and K. Makishima^{1,4}

¹RIKEN, Cosmic Ray Laboratory, 2-1 Hirosawa, Wakoshi, Saitama, 351-0106 Japan; JSPS fellow

²INAF, Osservatorio Astronomico di Bologna, via Ranzani 1, 40127 Bologna, Italy

³INAF, Osservatorio Astrofisico di Arcetri, L.go E. Fermi 5, 50125 Firenze, Italy

⁴Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033

1. INTRODUCTION

The signature of the star formation (SF) history of a galaxy is imprinted in the abundance patterns of its stars and gas. Determining the abundance of key elements released in the interstellar medium (ISM) by stars with different mass progenitors and hence on different time scales, will thus have a strong astrophysical impact in drawing the global picture of galaxy formation and evolution (McWilliam, 1997, ARA&A, 35, 503). It also offers the unique chance of directly witnessing the enrichment of the ISM (Maeder & Conti, 1994, ARA&A, 32, 227). Metals locked into stars give a picture of the enrichment just prior to the last burst of SF, while the hot gas heated by SNe II explosions and emitting in the X-rays should trace the enrichment by the new generation of stars.

We have started a project to measure the metallicity enhancement in a sample of starburst galaxies, for which we obtained high resolution infrared (J and H band) spectra with the 3.6 m Italian Telescopio Nazionale Galileo (TNG) and with the ESO VLT, and both proprietary and archival data from the XMM-Newton and Chandra missions. Our sample comprises M82, NGC253, NGC4449, NGC3256 and the *Antennae*, sampling two orders of magnitude in star formation, as it ranges from the 0.3 M_{\odot}/yr of NGC4449 to the $\sim 30M_{\odot}/\text{yr}$ of the *Antennae* and NGC3256.

Preliminary results for M82 were achieved with the available XMM-Newton archival data, and hinted for a confirmation of the expected scenario in which the gaseous component has a higher content of α -elements than the stellar one, and a similar content of Fe (Origlia et al., 2004, ApJ 606, 862). However, some new issues were posed, since we found a very low abundance of O and Ne with respect to other α -elements (e.g., O/Mg ~ 0.2 , Ne/Mg ~ 0.3) in the hot gas present in the central ($< \sim 1$ kpc) regions of M82, which could not be satisfactorily explained. Thus we were granted a deeper observation of M82, whose preliminary results are presented in the following.

2. MAPPING THE CHEMICAL ELEMENTS THROUGH NARROW-BAND IMAGING

The MOS and PN cameras onboard XMM-Newton have a moderate energy resolution (FWHM $\sim 70 - 80$ eV at 1 keV), which allows the use of narrow-band imaging to infer the distribution of chemical elements throughout the galaxy. Among the most prominent spectral lines lying around ~ 1 keV, we consider here the Ne X line at 10 \AA because this element, together with O, posed the main problems in our previous work. Unfortunately, it is not possible to consider lines from O, since the MOS resolution is rapidly degraded at energies $< \sim 0.6$ keV, and the enlargement of the band needed to take account of the instrumental effects would make an image in the O band seriously contaminated by continuum emission.

In order to extract information about abundances, the line-band images should be normalized by accounting for the continuum emission. We perform this correction by dividing each line-band image by a smoothed 0.5–2.0 keV band image. Results from spatially-resolved spectroscopy confirmed that once this correction is applied, the line-band images do trace the chemical abundances.

Fig. 1 (left panel) shows the Ne abundance distribution map with superimposed contours from 0.5–2.0 keV emission. Ne is clearly concentrated in two separated regions, north and south of the galaxy center.

3. SPATIALLY RESOLVED SPECTROSCOPY

We present here the preliminary analysis conducted on the southern outflow, making use of EPIC data. We divided the southern outflow in five regions, in order to study the different properties of the hot gas as it flows and/or is heated from the central starburst towards the intergalactic space. The regions are numbered from S1 to S5 with increasing height above the galactic plane, and are shown in Fig. 1 (right panel). The spectra were extracted from the

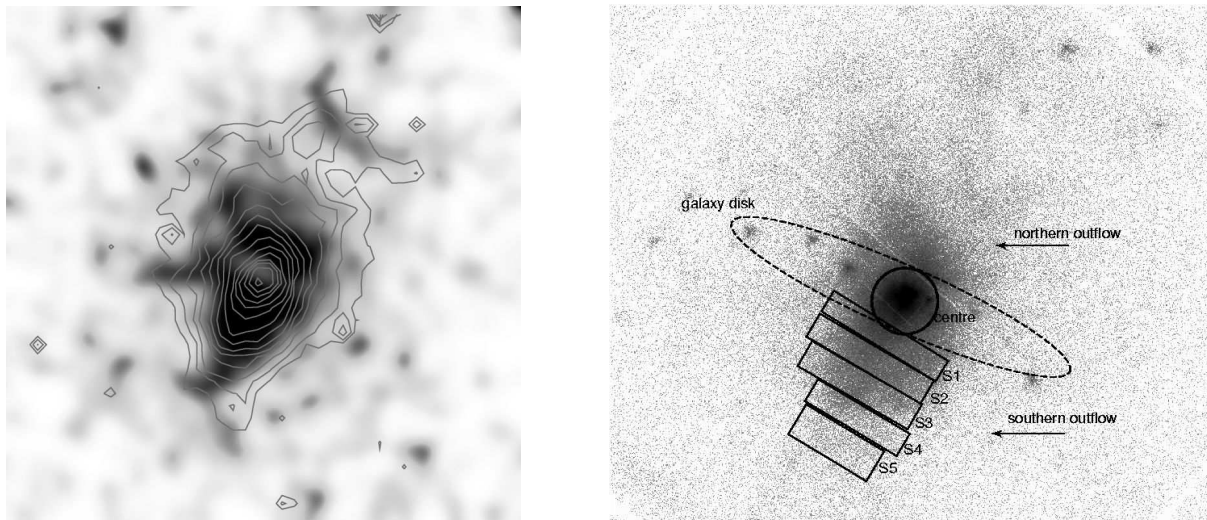


Figure 1. **Left:** *Ne X* abundance map. Gray scale: line/continuum flux ratio, tracking *Ne* abundance; darker means more abundant. Contours: 0.5–2.0 keV emission. **Right:** Image of 0.5–10 keV emission with a sketch of the regions used in the spectroscopical analysis.

Table 1. Chemical abundances in different regions with 90% errors. The abundances are given in solar units, i.e. Fe/Fe_{\odot} , following the Grevesse & Sauval (1998, *Sp.Sci.Rev.* 85, 161) scale. Region S4 is not shown since it falls mainly on CCD gaps. The “stars” region shows the results from infrared spectroscopy, while the “centre” region is referred to the PN+RGS data analysis in Origlia et al. (2004). The average height above the galactic plane is reported, assuming a distance of 2.94 Mpc (de Vaucouleurs et al., “Third reference catalogue of bright galaxies”, 1991, assuming $H_0 = 70$).

region	height (kpc)	Fe	O	Ne	Mg	Si	S
centre		$0.43^{+0.12}_{-0.08}$	$0.26^{+0.15}_{-0.09}$	$0.45^{+0.17}_{-0.12}$	$1.36^{+0.32}_{-0.26}$	$1.49^{+0.32}_{-0.26}$	$1.42^{+0.48}_{-0.40}$
S1	0.6	0.48 ± 0.01	0.57 ± 0.04	0.85 ± 0.05	1.33 ± 0.04	1.12 ± 0.05	0.75 ± 0.10
S2	1.0	0.57 ± 0.02	0.64 ± 0.04	1.26 ± 0.07	1.73 ± 0.07	1.33 ± 0.09	0.75 ± 0.17
S3	1.5	0.88 ± 0.04	1.04 ± 0.07	2.21 ± 0.14	3.06 ± 0.15	2.06 ± 0.17	1.29 ± 0.33
S5	2.5	0.78 ± 0.08	1.71 ± 0.16	3.31 ± 0.35	4.09 ± 0.48	2.65 ± 0.74	$0.53^{+1.93}_{-0.53}$
stars		0.5 ± 0.2	$1.0^{+0.5}_{-0.3}$	—	$1.1^{+0.4}_{-0.3}$	$1.1^{+1.0}_{-0.5}$	—

MOS (0.5–8.0 keV) and PN (1.0–9.0 keV) data, and fitted with a multi-temperature “mekal” thermal plasma model whose differential emission measure (DEM) is described by a 6th order polynomial in the 0.1–10 keV energy range. Background spectra were extracted from the blank-sky data files (Read & Ponman, 2003, *A&A*, 409, 395) after normalization to the background levels observed in the M82 data.

The best-fit chemical abundances are shown in Table 1 along with results from our previous paper (Origlia et al., 2004, *op. cit.*) relative to X-ray (EPIC and RGS) and infrared data for the central regions, marked in the Table as “centre” and “stars”, respectively. No significant changes are found in the temperature of the plasma. The only region whose spectra require absorption in excess of the Galactic value is S1. Our previous finding, that the inner region of M82 is somewhat devoid of the lighter α -element, is thus confirmed. Moreover, it is found that these elements are rather to be concentrated in the outflow. On the other hand, the heavier elements (Mg, Si, S) while following a similar spatial pattern seem to be more evenly distributed.

4. DISCUSSION

In M82 both the hot gas and the stellar phases trace a very similar Fe abundance. Indeed, since Fe is mainly produced by type Ia supernovae (SN), it is expected to be released in the ISM only after ~ 1 Gyr from the local onset of star formation. At variance, α -element (O, Ne, Mg, Si, S) are predominantly released by type II SN with massive progenitors on much shorter time scales. The overall α -element/Fe enhancement in the innermost region of M82 is consistent with a standard chemical evolution scenario only for heavier elements (Mg, Si, S).

However, the lighter elements (O, Ne) show a different distribution, in which the inner regions of the galaxy appears somewhat devoid of these metals, while in outer parts of the outflow they are found to be enhanced as the heavier α -element. When the entire sample of galaxies will be analyzed, we will better understand whether the bipolar distribution of O and Ne is peculiar of M82 or is a common feature in starburst galaxies.